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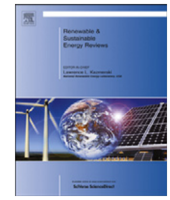

Substitution among energy sources: An empirical analysis on biomass energy for fossil fuel of China

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A R T I C L E I N F O

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Nowadays, there are several problems to be urgently addressed for China: rural development, energy security and environmental protection. To promote biomass energy as a substitution for traditional fossil fuel is one of important ways to solve these problems. Data of China industrial departments for duration of 1987–2009, making use of AES and MES, is selected for the empirical analysis. The results shows that: (1) China's demand for biomass will increase with the decrease from the own-price, while traditional fossil fuel prices and demands varying to the same direction shows that price-induce conservation has nothing to do with reducing consumption. (2) CPE proves that biomass is an effective substitution for traditional fossil fuel factor, the reducing in biomass prices will lead to the decrease of demand for traditional fossil fuel. (3) MES indicates that with the reduction of biomass prices, the cost structure of energy consumption of traditional fossil fuel will be reduced, the trend of net substitution is enhancing which proves that price-induce conservation will promote the substitution. In conclusion: China's fossil fuel of oil and coal presents a certain feature of "Giffen goods" or "inferior goods" for duration of 1987–2009, while bioenergy, as one of renewable energy, is shown as "normal Goods" characteristics; bioenergy is an effective substitution for traditional fossil fuel energy products.

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1. Introduction

China today has become the second largest energy resources producing and consuming country in the world in 2009. At the same year, China becomes the net importer from the country of coal exportation. According to BP Statistical Review of World Energy 2012, in 2011, the global energy consumption grew by 2.5%, which was close to the historical average. It's remarkable that China alone accounted for 71% of global energy consumption growth. The consumption of energy resources in China still mainly relied on coal and oil which together account for 90% approximately. In 2011, China's crude oil production was 203, 645,100, with a year-on-year increase of 0.32%, and the degree of dependence on imported crude oil was 56.5%, which makes China still be the world's second-largest oil consumer. In 2011 as well, The output of China's raw coal was 3.52 million tons, with an increase of 280 million tons, whose increment reached the highest level in history of China, and its degree of dependence on foreign increased from 7% in 2000 to 14% in 2011, so coal will still become the dominant energy in China in the next 20 years.

It is critical time for China to continue the economic and social development. On one hand, China is required to take a sustainable development path which includes the development speed matching the life quality improvement and the economy development harmonizing the population, resource and environment. On the other hand, China now faces several problems that are urgently required to be solved, such as energy resources security, environment protection and rural development etc. Accompany with the world economic recovery and the economic growth of China, the gap of supply and demand of energy resources in China will increase further. The problems of energy resources security and low-carbon development in China become more and more important because of the following questions: the further rising of world energy prices, the increasing of China energy requirement, the uncertainty of geopolitics, the risk of RMB exchange rate, and the commitment of China government for carbon emission reduction in Copenhagen Climate Change Conference. At the same time, economic growth mode transformation and new socialist countryside construction bring forward the actual demands for promoting the rural development and improving the peasant income. Therefore, the great development of biomass energy has the significantly strategic meaning for solving the bottleneck problem, which restricts development for China and limit to realize the commitment of China government after Copenhagen Climate Change Conference.

China is a large agricultural country with abundance of biomass energy resources. According to the preliminary estimation from relevant department, the total weight of straw coming from the wasted crops is about 100 million tons each year in rural areas, which can convert into the standard coal of 50 million tons. In accordance with calculations above, the conversion can reach the amount of standard coal between 700 million tons and 1 trillion tons in 2020. Therefore, biomass energy resources can substitute for the traditional fossil fuel by using biomass resource fully before it is thrown away or burned arbitrarily, which can prevent the environment from being destroyed by agricultural waste. It is an effective way to make peasants and enterprise gain economic benefit during the process of biomass energy transformation. Such would bring us three good results: making up the absence of energy supply, protecting the environment and adding the income of peasants. At present, the development of biomass energy falls behind, relatively comparing with the development of solar, wind and hydropower. According to the main development target written in "National Guideline on Medium & Long Term Program for Renewable Energy in China", the utilization quantity of biomass energy would occupy 1% of the amount of the primary energy consumption in 2010, and it will reach 4% by 2020. China must promote the speed of exploitation and utilization of biomass energy by substitution for fossil fuel in order to realize this target.

2. Literature review

Nowadays, some scholars have preliminarily researched the energy substitution issues. They mainly investigated the following aspects: the development path on energy substitution, the society influence on energy substitution and the welfare analysis of energy substitution etc., in which the study of factor substitution in production function and cost function becomes the primary breakthrough point [[21,22].

The research generally starts from the two aspects:

One is the research on the substitution for energy resources, which means to determine the substitution elasticity of energy resources by different input factor such as capital, labor and raw material etc. Among the investigations, the research of Bemdt and Wood [1–5], Hudson and Jorgenson [6] showed energy resources could substitute labor. The study of Griffin and Gregory [9] showed energy resources could substitute capital. Because some policies encouraged new material or capital to save energy resources, the substitution between capital and energy resources affected the validity of these policies. Furthermore, whether the substitution could exist from the view of medium and long term or not was still a question. After that, by using panel-data in seven countries from 1963 to 1974, the Ozatalay et al. [11] estimated the Allen partial elasticity of substitution coefficient and demand elasticity, and got the conclusion that other input factors could substitute energy resources except for raw material, which meant even if energy resources were restricted, the economy could still grow sustainably, and capital was a good substitution for energy resources from view of long term. Thompson and Taylor [15] calculated Morishima Elasticity of Substitution (MES) with the parameter estimation, which yielded that capital was an ideal substitution for energy. In China, Lu Chengjun [26] analyzed the issues on the substitution of capital and labor for energy resources, and discussed the influence between technical effect and output effect, then got that the elasticity of energy own-price was less, the existence of two effects promoted that labor substituted energy resources and capital had the obvious mutual complementarity with energy resources. [27], eliminating the factor of labor, got the conclusion that the substitution between capital and energy resources was uncertain by adopting the production function of CES and C–D. In addition, some economists once made a research on 2500 enterprises, and the result indicated the decreased effect on usage amount of energy resources can reach 55% by adjusting the prices of energy resources, while the other 17% was the result of technical research and development. If considering the effect of technical research and development by changing the prices of energy resources, the effect on decreasing the usage of energy resources by the prices of energy resources would be more obvious.

The other aspect is on the issue of *interfuel substitution* or *substitution among energy resources*, which means to research the substitution relationship among the different energy resources. Up to now, the scholars at home and abroad made a few progress on the normative and empirical analysis of interfuel substitution, and got a few interrelated research achievements. The foreign scholars are keen on discussing the feasibility and rationality of the interfuel substitution, so there are some achievements on the research methods and modeling, while the domestic scholars mainly focus on the purpose of environmental protection, economic growth and industrial development. There have been some studies investigating substitution among energy resources and

the demand for energy—for example, Kurt Kratena [15], Hengyun Ma et al. [16,18], Serletis and Shahmoradi [17]. Among them, by using the model of Translog and Logit and making French and England as the research target, Maissant [12] discussed the issue of interfuel substitution among steam coal, electricity and oil for duration of 1987–2002 in two countries from the view of CPE, and get the conclusion that oil was the weak substitution for steam coal as same as oil for electricity in two countries by using the method of empirical analysis, and the substitution among energy resources has a strong characteristic of uncertainty from the view of policy. Apostolos et al. [20] used the locally flexible translog functional form to investigate the demand for energy and interfuel substitution in the United States and to provide a comparison of their results with most of the existing empirical energy demand literature. And then Apostolos et al. [19] also reported short- and long-run estimates of aggregate interfuel substitution for a number of OECD and non-OECD countries. After studying long-run growth in a multi-sector economy with non-renewable resource use and endogenous innovations, Bretschger and Smulders [21] found that poor input substitution need not be detrimental for sustainable growth; on the contrary, combined with resource depletion it fosters structural change, which helps to sustain research investments. Fredrik Pettersson and Söderholm [22] investigated price-induced switching behavior between fossil fuels in the European power sector, employed a Generalized Leontief model using data across eight countries over the period 1978–2004, found notable short-run interfuel substitution, and particularly between oil and gas, and their results showed that public policies have had profound impacts on fossil fuel choices. For special problems during China's development process, Hongliang et al., [23] analyzed the elasticity of interfuel substitution in the steel industry of China, and the result indicated that the steel industry of China could realize the increase of total factor productivity in industry by substituting coal for oil, natural gas and electricity. [24], with the Lotka–Volterra model and Parameter Gray Estimation method, used the time series data of electric power generation of renewable energy and thermal power generation in China during 1994–2010 to analyze empirically the substitution relationship between thermal power generation technology and renewable energy power generation technology. And their results showed that thermal power generation technology and renewable energy power generation technology play synergistic roles; in the condition of current technology level, when thermal power technology dominates, it would not be replaced by renewable energy power generation technology in the near future. What is more, Xingang and Pingkuo [25] also analyzed the status quo from two aspects of market and policy environment as the basis of the research.

From the research of scholars above on substitution among energy resources, we know that the correlated research mainly focuses on the substitution for energy resources (they paid much attention on substitution of capital for energy resources). Whereas, there is extremely few research on substitution among energy resources, especially for China, and there is almost a blank for research on renewable energy resources substituting for fossil fuel. Nevertheless, in 2009, the company of Petro China, GD, China Huaneng Group, China Datang Corporation and the China Power Investment Corporation were the first to enter the renewable energy industry. Among these industries, some have developed rapidly, and others are still in its infancy.[1] Regardless of the global economic environment, the development of interfuel substitution is always paid attention to by the government.[2] So, in 2011, the Ministry of Industry and Information Technology of the People's Republic of China (MIIT) stressed that during the period of economic transition, China should be wary of the higher dependence on foreign energy, so that the experts once again recommended and encouraged the development of interfuel substitution.[3] Therefore, an in-deep and systemic research for the issue on substitution among energy resources of China must be necessary. China should pay much more attention to the issue on renewable energy substituting for fossil fuel, especially during the execution process of National Guideline on Medium & Long Term Program for Renewable Energy in China. Whereas, by analyzing the market of energy resources in China and utilizing Translog model based on AES model and modified by MES, this paper will work on interfuel substitution of China biomass energy for traditional fossil fuel from the view of industrial departments, and will make the empirical analysis on the basis of the research work. The theory research, the measurement, the calculation of relevant data and the result of empirical analysis in the paper, not only help us to develop the further research on substitution among energy resources, but also make up the research blank in this aspect. At the same time, it will offer a beneficial reference for important theory and the design of policy framework, aiming to realize the goal of development and planning on medium and long term program for national renewable energy in China.

3. Econometric methods

Substitution is the result of the endogenous reason of price-induced. In accordance with the basic assumption of Neoclassical Economics, the increase of total output of economy represents the increase of society welfare (Renou-[12]). Considering the present consumption of energy resources in China mainly relying on coal and oil, moreover, utilizing the model of Allen Elasticity of Substitution (AES) and Morishima Elasticity of Substitution (MES) as well as modifying the model, this paper aims at interfuel substitution of biomass energy for fossil fuel (except natural gas) according to the requirement of separability set by the model.

3.1. AES model

Translog cost function is:

$$\ln C = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} \ln p_i \ln p_j \tag{1}$$

where $i(1 \le i \le 3)$ includes oil, coal and biomass energy;

α,β unknown parameter;

p_i means the price of input factor.

In addition, the input prices of given factor are homogeneous of degree one:

$$\begin{cases} \sum_{i=1}^{n} \alpha_i = 1 \\ \sum_{i=1}^{n} \beta_i = \sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} = 0 \end{cases} \tag{2}$$

$$\text{Total cost derivation of the price is}: \frac{\partial \ln C}{\partial \ln p_i} = \sigma_i + \sum_{j=1}^{n} \beta_{ij} \ln p_j \tag{3}$$

$$\text{Shephard lemma}: x_i = \frac{\partial C}{\partial p_i} (i = \mathrm{O,C,B}) \tag{4}$$

[1] http://stock.jrj.com.cn/2009/12/0306406570923.shtml.
[2] http://finance.ifeng.com/news/20091015/1338351.shtml.
[3] http://news.sina.com.cn/c/sd/2011-08-04/114522933676.shtml.

Table 1
The internal mutual relationship among energy resources and price elasticity.

	CPE	MES
Mutual complementary	<0	<0
Substitution	>0	>0
Uncertainty (MES substitution, CPE mutual complementary)	<0	>0

the percent of factor No.i cost in total cost can be calculated from the formula (4) is:

$$s_i = \frac{p_i x_i}{C} = \frac{p_i\left(\frac{\partial C}{\partial p_i}\right)}{\sum_{j=1}^{n} p_j\left(\frac{\partial C}{\partial p_j}\right)} = \alpha_i + \sum_{j=1}^{n} \beta_{ij} l\, np_j \quad (5)$$

then from the Allen partial elasticity of substitution:

$$\sigma_{ij} = C \times \frac{\frac{\partial^2 C}{\partial p_i \partial p_j}}{\left(\frac{\partial C}{\partial p_i}\right)\left(\frac{\partial C}{\partial p_j}\right)} \quad (6)$$

we can get:

$$\begin{cases} \sigma_{ij} = \frac{\beta_{ii}+s_i \times s_j}{s_i \times s_j} \\ \sigma_{ii} = \frac{\beta_{ii}+s_i^2-s_i}{s_i^2} \end{cases} \quad (7)$$

The Allen partial elasticity of substitution in formula (6) is:

$$\eta_{ij} = CPE_{ij} = s_j \times \sigma_{ij} \quad (8)$$

where CPE_{ij} is the absolute elasticity of substitution.

3.2. MES model

As a sort of Hicks marginal rate of substitution in MES model, the elasticity of substitution, or is called net elasticity of substitution, is used to analyze the relative substitution among the factors of energy resources at the level of macro and micro. The decrease of production j price may lead to the increase of total consumption of productions. However, it does not mean that the $i$consumption per unit will increase relative to the change of j price, on the contrary, it may decrease relatively.

Based on MES model and modifying it according to Hicks theory, the calculation formula of MES substitution elasticity is:

$$MES_{ij} = \frac{\partial \ln x_i}{\partial \ln p_j} - \frac{\partial \ln x_j}{\partial \ln p_j} \quad (9)$$

thereby it is:

$$MES_{ij} = \eta_{ij} - \eta_{jj} \quad (10)$$

According to Hicks theory, the cross-price elasticity $\eta_{ij}$is CPE_{ij}, which is equal to total effect; the own-price elasticity $OPE_{jj} = \eta_{jj}$, is equal to income effect; the MES_{ij} elasticity is substitution effect.

Based on the AES model and modified by MES, we know the internal mutual relationship between price elasticity and energy resources. According to Table 1, we can judge the internal mutual relationship among energy resources.

4. Empirical analysis

4.1. Data processing

To analyze the interfuel substitution among energy resources by utilizing the Translog cost function, the key point is the measurement and calculation for the price of biomass energy as well as fossil fuel such as oil and coal. We can get the prices of coal and oil according to the statistical yearbook of BP energy resources and adjust them by utilizing the different levels of exchange rate. However, we cannot obtain the price data of biomass energy directly. We need to analyze biomass energy from agricultural and forestry department, the crop straw of energy resources and the dejecta of livestock in order to obtain the data. Before analyzing biomass energy, we need to consider, on one side, the real national conditions (the principle of "do not use crop as material which people can eat, do not use the land where crop needs") and improve the industrial development of biomass energy in stages. At present, the degree of scale production for methane in China is still very low and the development of liquid biomass fuel is limited by national conditions and industrial policy. Therefore, the industry of biomass energy utilizing the waste of agricultural and forestry has the scale and the potential, which shows that biomass energy is able to substitute for the fossil fuel. On the other side, we need to consider the data principal such as the availability, possibility of analogy and coherence. Hence, the research of paper is based on biomass energy transformed from the waste of agricultural and forestry. Considering the present situation of development, we select the relevant serial data for duration of 1987–2009 in China to make the research general and analyze the substitution of biomass energy for fossil fuel.

4.1.1. Energy resource price

(1). The price of biomass energy is p_B which is an unobtainable data according to the relevant statistical yearbook. The energy resources mainly come from the transformation of two resources: the straw of crop resources (CR) and the biomass of forestry resources (FR). We can estimate the price of biomass energy (p_B) according to the local investigation and the price of crop and timber in past years, and use the formula (11) to get it:

$$p_B = \theta p_{\mathrm{CR}} + \omega p_{\mathrm{FR}} \quad (11)$$

where θ and ω means the percent of CR and FR in the total biomass energy, and there sets $\theta + \omega = 1$.

(2). The oil price is p_O. Considering the oil consumption and the dependency on import, and utilizing the statistical yearbook of BP (2009), we make the data processing of oil prices in China according to different levels of exchange rate in past years.

(3). The coal price is p_C. At present, the coal prices in China don't have the official standard. The prices of standard coal are often affected by the international prices of crude oil, and the prices also appear different because of the difference of shipping charge and warehouse expense. At the same time, the supply gap of coal is often made up by importing coal from the international market. Therefore, the paper adopts the same method of oil prices to treat the coal price and use the import prices of international coal obtained from statistical yearbook of BP (2009) in order to making sense.

4.1.2. Energy resources stock

(1). The biomass energy stock, like the price of biomass, is also an unobtainable data. Considering the distribution of biomass resources and the production technology of biomass energy, we adopt the conversion formula (12) to calculate the data with the reference of "the statistical yearbook for duration of 1986–2009 in rural of China"

$$\begin{cases} \mathrm{CR} = \sum_{i=1}^{l} Qc_i \times r_i \\ \mathrm{FR} = \sum_{j=1}^{h} Qf_j \times \tau_j \end{cases} \quad (12)$$

where CR is the straw stock of crop resources, and FR is biomass stock of forestry resources;
Qc_i is the total amount of crop resources, $Qf_j$is the total amount of forestry resources.
r_i is the conversion coefficient for crop No. i, and $\tau_j$is the conversion coefficient for forestry resource no. j;
l is the type of crop and $h$is the type of forestry.
The conversion coefficient is an empirical data and the different scholars give different calculations according to the different research targets. However, the conversion rate for biomass resources in same type at the different area is the same in general. So, by integrating the present results and data, we select the minimum value of conversion rate as the calculation benchmark. Otherwise, the relevant output of biomass resources can obtain from the statistical yearbook of China and the rural statistical yearbook of China.

(2). The oil stock can be collected from the statistical yearbook of BP (2009).
(3). The coal stock can be obtained from the statistical yearbook of BP (2009), and then convert the oil equivalent calculated in the unit of mtoe into the stock calculated in the unit of ton.

4.1.3. Energy cost

When utilizing the cost function of Translog to analyze the data, it needs to calculate the total cost of biomass energy, oil and coal. The calculation formulas are:

$$\text{Total cost of biomass energy}: C_B = p_{CR} \times CR + p_{FR} \times FR \quad (13)$$

$$\text{Total cost of oil}: C_O = p_O \times Q_O \quad (14)$$

$$\text{Total cost of coal}: C_C = p_C \times Q_C \quad (15)$$

4.1.4. The other relevant data

During the research, we need to get the TC data of total cost of energy resources in order to calculate their shares s_B, s_O and s_C. However, the input of the oil, coal and biomass energy used in the mutual production is very little, the intermediate input of these aspects relative to the total consumption of energy resources can be ignored, and the total cost of energy resources is regulated by the final demand of industrial departments in China. Hereby, the total cost can obtain as the formula (16).

$$TC = \sum_{i=1}^{n} C_i \quad (16)$$

We can calculate the total consumption of biomass energy, oil and coal by industrial departments in China according to formula (16).

4.2. Empirical results

According the above analysis, we make the calculation and get the two results: the cost share of energy resource and the corresponding logarithm price index. See Table 2.

Based on the data of Table 2, we make the quantitative analysis to $s_i = \alpha_i + \sum_{i=1}^{n} \beta_{ij} \ln p_j$by using the relevant software, and get the results: the coefficient of determination in regression equation is high and the regression coefficient is significant. The model exits the autocorrelation under the significant level of 5% according to the DW statistic table. Furthermore, we choose the White Test and the BG Test and then LM test (pl). Then we can find there is no autocorrelation after modification, results also pass the relevant checks such as goodness of fit, multicollinearity, heteroscedasticity and auto-correlation test. At the same time, the statistical quantity of determination coefficient such as R^2,t,F reaches the ideal level. See Table 3.

Table 2
Factor cost share of energy resources and logarithm price index.

Year	SB	SO	SC	LNPB	LNP0	LNPC
1987	0.022658	0.451396	0.525946	0	0	0
1988	0.027719	0.369264	0.603017	0.030563	−0.25183	0.086958
1989	0.028035	0.386362	0.585603	0.047147	−0.0873	0.183395
1990	0.024117	0.447642	0.528241	0.066691	0.363037	0.354835
1991	0.027334	0.407548	0.565118	0.153165	0.2579	0.440622
1992	0.032637	0.414379	0.552984	0.257045	0.228997	0.42426
1993	0.051649	0.389377	0.558974	0.55863	0.113673	0.415785
1994	0.046707	0.359898	0.593395	0.725381	0.420619	0.81735
1995	0.064742	0.353033	0.582225	0.866811	0.434173	0.840392
1996	0.106353	0.375104	0.518543	0.905195	0.595109	0.857545
1997	0.137649	0.383793	0.478558	0.917669	0.490174	0.810749
1998	0.173081	0.317926	0.508993	0.875469	0.066961	0.713998
1999	0.157351	0.424544	0.418105	0.841864	0.391049	0.607373
2000	0.127087	0.539282	0.333631	0.89115	0.81888	0.618079
2001	0.128927	0.460149	0.410924	0.889734	0.637289	0.801879
2002	0.132158	0.501736	0.366106	0.86536	0.645027	0.643209
2003	0.119026	0.495809	0.385165	0.913528	0.764176	0.740428
2004	0.091927	0.470892	0.437181	1.020961	1.02088	1.19358
2005	0.079577	0.502274	0.418149	1.100909	1.331315	1.309803
2006	0.078848	0.525216	0.395936	1.158831	1.450581	1.285141
2007	0.080395	0.523566	0.396039	1.202247	1.469594	1.276619
2008	0.064524	0.434628	0.500848	1.301788	1.647464	1.842248
2009	0.088153	0.388389	0.523458	1.21971	1.178949	1.515355

We can get the elasticity value of own-price, absolute elasticity of cross-price and net elasticity of cross-price of biomass energy, oil and coal for the duration of 1987–2009 in China by utilizing the model of AES and MES. See Table 4 and Table 5.

4.3. Analysis of empirical results

4.3.1. The analysis on elasticity of own-price of biomass energy, oil and coal

(1) Shown as Fig. 1, the elasticity of own-price of coal and oil in China has a stable trend of fluctuation for duration of 1987–2009, whereas, the elasticity of own-price of biomass energy has an unstable trend of fluctuation. The elasticity of own-price of coal fluctuates between 0 and 0.1 stably; oil is similar with coal, fluctuating between 0 and 0.2 stably. The elasticity of coal and oil does not appear the trend of increase or decrease due to the price inducement. The elasticity of own-price of biomass energy appears the trend of decrease obviously for duration of 1987–1996, whereas, appears the stable trend of development for the fluctuation between −0.5 and −0.65 for duration of 1997–2009. Therefore, by considering the industrial development course of biomass energy in China and World and the complete and scientific character of the relevant statistic data, the paper analyzes the elasticity of own-price of biomass energy for duration of 1997–2009 in China without loss of the economics meaning of elasticity of own-price.

(2) The elasticity of own-price of biomass energy is −0.44406, and its absolute value far exceeds 0.07679 (the elasticity of own-price of oil) and 0.02082 (the elasticity of own-price of coal). Hence, the biomass energy is a sort of energy with bigger elasticity of own-price compared with oil and coal and its demand is affected more obviously by the variety of prices. The elasticity of own-price is equal to the income effect according to Hicks theory. If the elasticity of own-price is a minus value that means the income effect is a minus value, it indicates the biomass energy has the character of “normal goods” and the trend of alteration between price and demand amount is in the contrary direction.

Table 3
The estimation value of relevant parameter and the result of modification.

	SB LNPB	SB LNPO	SB LNPC	SO LNPB	SO LNPO	SO LNPC	SC LNPB	SC LNPO	SC LNPC
OLS coefficient	0.202184 (0.0000)	−0.032083 (0.1883)	−0.101495 (0.0073)	0.041617 (0.0318)	0.272839 (0.0000)	−0.286724 (0.0000)	−0.243801 (0.0000)	−0.240756 (0.0000)	0.38822 (0.0000)
R-squared		0.779624			0.944702			0.864393	
Adjusted R-squared		0.744828			0.935971			0.842981	
F-statistic		22.40541			108.1983			40.37022	
Prob (F-statistic)		0.000002			0.0000			0.0000	
White Heteroskedasticity Test	F-statistic	2.386316	(0.077058)	F-statistic	0.686017	(0.663818)	F-statistic	2.323546	(0.083319)
	Obs*R-squared	10.86195	(0.092738)	Obs*R-squared	4.706198	(0.582009)	Obs*R-squared	10.70928	(0.097788)
Breusch–Godfrey serial correlation LM Test	F-statistic	7.496122	(0.004634)	F-statistic	2.641818	(0.100215)	F-statistic	5.891213	(0.011382)
	Obs*R-squared	10.77829	(0.004566)	Obs*R-squared	5.453492	(0.065432)	Obs*R-squared	9.415321	(0.009026)
Dependent variable: RESID	RESID (−1)	0.844461	(0.0015)	RESID (−1)	0.546491	(0.0387)	RESID (−1)	0.74289	(0.0051)
	RESID (−2)	−0.281105	(0.2571)	RESID (−2)	0.020932	(0.9488)	RESID (−2)	−0.036826	(0.8960)
Ar (1)	0.026155 (−0.5613)	−0.04084 (0.0119)	−0.029968 (0.1431)				−0.00595 (0.9103)	−0.189407 (0.0000)	0.252397 (0.0000)
R-squared		0.922333						0.968393	
Adjusted R-squared		0.904059						0.960956	
F-statistic		50.47113						130.2145	
Prob (F-statistic)		0.0000						0.0000	
White Heteroskedasticity test	F-statistic	0.30824	(0.922878)				F-statistic	1.042173	(0.437222)
	Obs*R-squared	2.414779	(0.877881)				Obs*R-squared	6.472807	(0.372358)
Breusch–Godfrey serial correlation LM test	F-statistic	3.482773	(0.057229)				F-statistic	2.903947	(0.085896)
	Obs*R-squared	6.976472	(0.030555)				Obs*R-squared	6.140635	(0.046406)
Dependent variable: RESID	RESID (−1)	0.643064	(0.0254)				RESID (−1)	0.580133	(0.0601)
	RESID (−2)	−0.028435	(0.9174)				RESID (−2)	0.132416	(0.6374)

Table 4
Elasticity of own-price and absolute price.

	Biomass energy	Oil	Coal
Biomass energy	−0.44406	0.18066	0.06961
Oil	−0.30832	0.07679	0.03035
Coal	−0.0564	−0.19184	0.02082

Table 5
Net elasticity of price.

	Biomass energy	
Oil	−0.38511	
Coal	−0.0722	
	Oil	**Coal**
Biomass energy	0.62471	0.51367

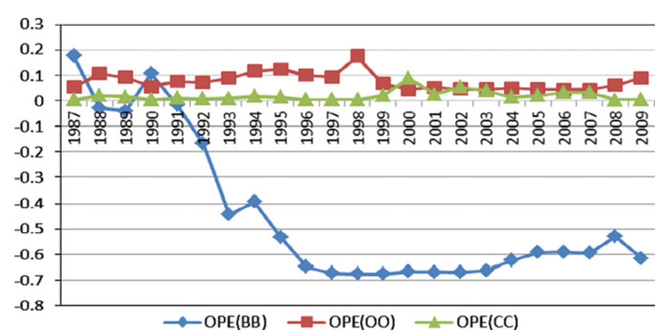

Fig. 1. The elasticity of own-price of biomass energy in China.

(3) The elasticity of own-price of oil and coal is 0.07679 and 0.02082, respectively, and it means that the income effect has the same trend of alteration with the price, which is the increase of price will lead to the increase of demand. From above we can know that china's fossil fuel of oil and coal presents a certain feature of "Giffen goods" or "inferior goods" for duration of 1987–2009, which means the price rises and the demand increases on the contrary. Therefore, it cannot decrease the demand of oil and coal if only depends on the price inducement.

(4) The elasticity of own-price of oil and coal is a positive value. The reason may come from the following: ① the inertia of time series; ② the self-restriction of Translog model; ③the pattern of economic growth which is driven by investment. For the market of energy resources in China, although the price of bulk commodity such as oil and coal keeps increasing, the pattern of economic growth driven by investment decides that the demand of oil and coal for the growth of China economy appears the certain rigidity. The demand of oil and coal for the increase of economy directly leads to the demand has the same direction of alternation with the price. The consumption of oil and coal enters into the "non-economic area". ④ The demand of oil and coal appears more rigidity and the application of technology is more mature compared with the inducement of price and technology of biomass energy.

4.3.2. The analysis on absolute elasticity of price of oil and coal by biomass energy

(1) From the analysis of Table 4, we can know the following information. The absolute elasticity of price of oil for biomass energy is −0.30832, whereas the absolute elasticity of price

of biomass energy for oil is about 0.18066; the absolute elasticity of price of coal for biomass energy is −0.0564, whereas the absolute elasticity of price of biomass energy for coal is about 0.06961. Analyzing the above reason, we can know the demand of oil increases when the price of oil rises, but decreases the demand of biomass energy at the same time. So the absolute elasticity of price CPE_{BO} is a minus value; when the price of biomass energy decreases, the demand of oil will decrease too, so the industrial department will use more biomass energy to substitute the oil and then the absolute elasticity of price CPE_{OB} is a positive value. At the same reason, we can analyze the relationship of absolute elasticity of price between biomass energy and coal. And we can know that biomass energy is the substitute for oil and coal in the consumption structure of energy resources in China according to the economic meaning of absolute elasticity of price.

(2) Fig. 2 shows that the substitution of oil and coal for biomass energy has a certain difference under the influence of the factor of price-induced. When facing the impact of price of international bulk commodity (or oil price), the biomass energy is one of the optimized substitutes without doubt. Furthermore, this substitution has a trend that becomes stronger after 2008.

(3) Fig. 3 shows that the variety of price of biomass energy has more influence on absolute demand of oil than coal. When changing the price of biomass energy, the variety of absolute demand of oil in China has more influent than the absolute demand of coal. By analyzing the reason, we know it is decided by the transmission mechanism of the traditional macro variable in China. The mechanism of "total installed capacity – industrial added value – GDP in-link mechanism" decides the rigidity demand of coal for the economy growth of China.

4.3.3. The analysis on net elasticity of price of oil and coal by biomass energy

(1) Known from Table 5, the net elasticity of price of biomass energy for oil and coal is −0.38511 and −0.0722, respectively, otherwise the net elasticity of price of oil and coal for biomass energy is 0.62471 and 0.51367, respectively. The result indicates that the substitution of oil and coal for biomass energy is very obviously in the structure of energy consumption in China. Also known from Fig. 4 and Fig. 5, with increasing of the trend of this substitution, the price inducement will further promote the substitution of biomass energy for oil and coal.

(2) Known from analysis on the net elasticity of price at the view of the composition of cost function and the consumption proportion in different energy resources, the proportion of oil and coal in total cost of energy resources consumption in China decreases correspondingly when the price of biomass energy reduces. At the same time, known from comparing and analyzing the elasticity of absolute substitution as well as net substitution of oil and coal for biomass energy, the function of elasticity of net substitution is far higher than that of elasticity of absolute substitution and the substitution of oil and coal for biomass energy is rather obvious.

(3) Shown from the further fast trend of net substitution and the bigger elasticity of net substitution of oil and coal for price inducement, the price inducement will obviously promote the substitution of biomass energy for oil and coal.

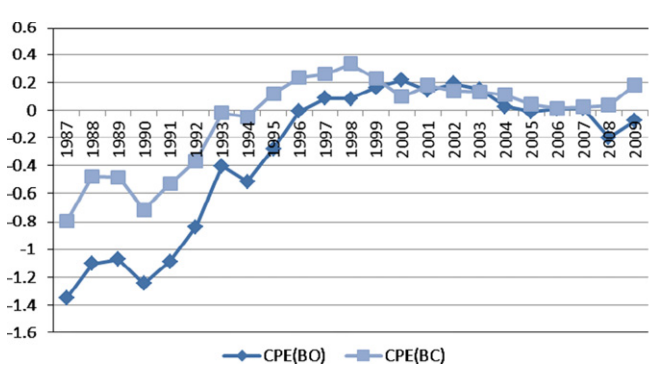

Fig. 2. The influence on absolute demand of biomass energy by price variety of oil and coal.

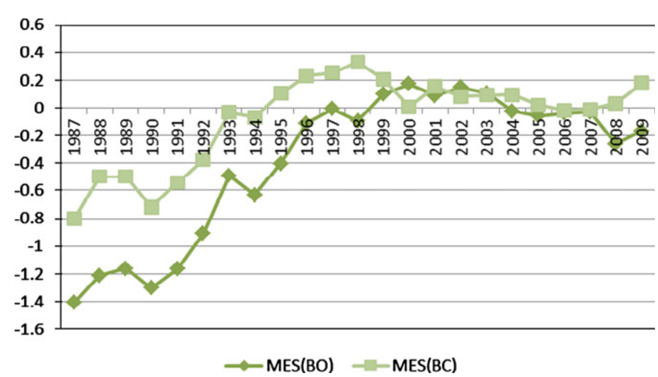

Fig. 4. The influence on net demand of biomass energy by the price variety of oil and coal.

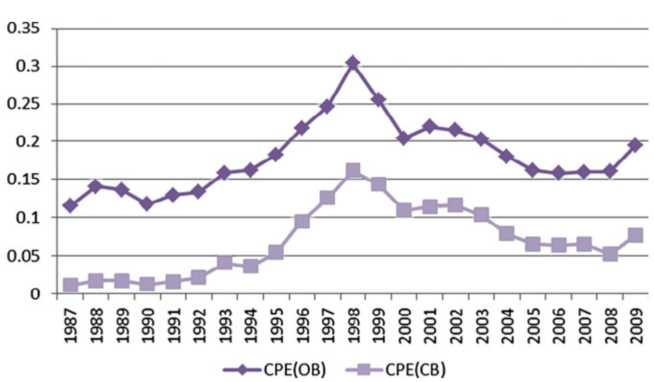

Fig. 3. The influence on absolute demand of oil and coal by price variety of biomass energy.

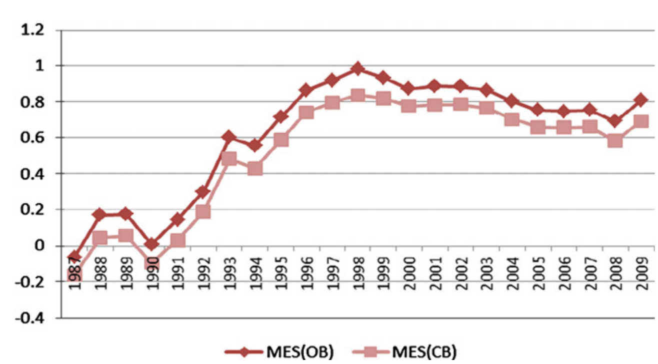

Fig. 5. The influence on net demand of oil and coal by the price variety of biomass energy.

(4) Comparing and analyzing Fig. 2 and Fig. 4 and then together seen from Fig. 1, the influence on net demand of biomass energy by the price variety of oil and coal is almost the same with that of absolute demand. Therefore, it shows the net substitution of oil and coal for biomass energy has the same trend with absolute substitution when the price of oil and coal faces the exterior impact.

5. Conclusion and policy implication

We can get the following conclusions according to the analysis on substitution of biomass energy for oil and coal in the market of China energy resources during 1987–2009:

(1) Oil and coal, which are two fossil fuels, present the feature of ''Giffen goods'' or ''inferior goods'' that means the demand will increase when the price rises. Therefore, the demand of oil and coal cannot be reduced only depending on the price inducement. While the biomass energy shows the character of ''Normal goods'' which means the relationship of price and demand is in the contrary direction. The reduction of the price of biomass energy will decrease the efficient demand of industrial departments for traditional fossil fuel such as oil and coal in China, and sequentially decrease the consumption proportion of oil in fossil fuel in China. The price inducement is favorable to increase the demand for biomass energy.
(2) Whether view from the point of absolute substitution or net substitution, biomass energy is the optimized substitution energy for oil and coal. In terms of the consumption of energy resources in China, the trend of absolute and net substitution of biomass energy for oil and coal becomes further stronger. Furthermore, the net substitution elasticity of biomass energy for oil and coal is much bigger than the absolute substitution elasticity and the net substitution is very obviously.
(3) For the biomass energy industry in China that just has the preliminary industrial base, the demand of biomass energy presents the obvious insensibility when the biomass energy faces the price shock of international bulk commodity such as oil and coal etc. When the price of biomass energy reduces, the demand of oil and coal has a higher sensibility that makes the demand of oil and coal decreases obviously. As ''normal goods'', biomass energy can satisfy demand theorem that means the price inducement can promote the substitution of biomass energy for oil and coal efficiently.
(4) The transmission mechanism of the traditional macro variable in China, which is ''*total installed capacity – industrial added value – GDP*'' in-line mechanism, decides the rigidity demand of China economy growth for coal. At the same time, the influence on absolute demand for oil by the price inducement of biomass energy is obviously bigger than that for coal. If the exorbitant price of biomass energy is constituted aiming to promote the industrial development, the absolute demand for oil in China will increase and the degree of the security of energy resources will reduce further.
(5) Seen from the short term, the policy of price support (or subsidy) for biomass energy industry constituting by China is helpful to realize the substitution of biomass energy for fossil fuel. Whereas, seen from the long term, considering the basic function of energy resources (including renewable energy and traditional energy) in national economy, the price of support and restriction executed on the market cannot conquer the non-efficiency caused by the market failure, on the contrary it strengthens the signal of false price. The false price inducement is not helpful to the substitution of biomass energy for fossil fuel, but it may promote the further increase of demand for coal and oil in China, and consequently threaten the security of energy resources in China.

At present, the development of biomass energy industry in China is in the crucial period. Although the industry development has the preliminary base and its potential is huge, the bottleneck problems in the development are also very complicated. Therefore, a mechanism of industry development including government guide, policy design and system construction will become the key point for the development of biomass energy industry for a period in the future.

5.1. Policy suggestions:

(1) Implement the market-oriented policy of industry development, formulate the consistent layout of industry development, improve the ability of coordination and execution of government, and ensure the efficient utilization of biomass energy and the research and development of relevant technology in order to promote the scale and industrial development of biomass energy industry.
(2) Because biomass energy has the character of ''Normal goods'', we can use the demand theorem efficiently and design policy combination scientifically and reasonably to promote the industry development in order to improve the allocative efficiency of resource market and energy market of biomass energy.
(3) For the biomass energy industry in China that just has the preliminary industrial base, the lower price is not helpful for biomass energy industry to form scale and industrialization and the higher price increases the absolute demand for oil and coal in China, and the security of energy resources will reduce further. Therefore, for the short term, the policy framework for development of biomass energy industry should be designed scientifically, the level of price or price subsidy for biomass energy should be formulated reasonably, and the pricing mechanism of biomass energy should be perfected. Then the methods that mentioned above can promote the quick development of biomass energy industry and the substitution of biomass energy for fossil fuel in order to realize the triple benefits of rural development, energy security and environment protection in China. For the long term, the price mechanism should play the basic function in the configuration of resources after the biomass energy realizing its scale and industrialization.
(4) In order to promote the scale and industrial development of biomass energy, the development mechanism of biomass energy industry suiting the situation of China should be researched, which means the development of biomass energy industry should be promoted at a steady pace in stages. In short term, the industrial development of biomass power generation and biogas should be promoted by utilizing the waste from agricultural and forestry and the dejecta of livestock. In medium and long term, the marginal land resource and the resources such as inshore and desert etc. can be developed and utilized reasonably, and the farming of energy crop and the algae resources should be developed stably to promote the industrial development of fuel ethanol and bioalcohol. Only by above methods, the substitution of biomass energy for fossil fuel such as coal and oil can be realized efficiently in order to protect the energy security of China.

Some questions and research aspects should be resolved and strengthened during the process of the local research and investigation:

1 The support for the relevant data of biomass energy is the key restriction on the research. At present, the relevant statistic

data of biomass energy industry is very few and the data used in the research only come from the local investigation results, combining with "China statistic yearbook", "the statistic yearbook of energy resources in rural of China" and the research data from the national engineering laboratory of whole set equipment of biomass power generation in our university as well as the estimation method being researched by the relevant scholars. Therefore, a set of scientific, reasonable and complete statistic system of biomass energy must be set up in order to promote the development of biomass energy industry in China.

2 The technical advancement is the result of market mechanism. The price of biomass energy is changed by the change in demand for biomass energy. On the contrary, the technical advancement is caused by the prices of biomass energy. However, the existence of rebound effect fully shows the interfuel substitution cannot be solved only depending on the technical advancement. If the technical advancement cannot decrease the consumption quantity of energy resources, and make it increasing on the contrary, then the substitution function will be reduced more.

3 Shown from the research of foreign scholars, the change of pattern for production and trade in biomass energy industry, which is in the preliminary phase of the industrial lifecycle, is the result of policy support without only depending on the technology. Therefore, the policy design of government will be the key direction of research for a time in the future in order to promote the development of biomass energy industry that just has the preliminary base.

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Further reading

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